

Magellan In Transition

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NASA's Magellan has project mapped 98 percent of Venus' surface with synthetic-aperture imaging radar, microwave radiometry, and radar altimetry. Additional experiments have provided several other data types, such as geodesy, atmospheric studies, and solar radio science. Magellan's mapping data are available in forms appropriate to users' needs, from many sources. They can be obtained both in photographic form and digitally on CD ROMs by researchers, through the National Space Science Data Center at Goddard Space Flight Center in Greenbelt, Maryland. Educators can find many forms of Magellan data at NASA's Teacher Resource Centers throughout the country. In addition, cataloged Magellan images, as well as video cassettes containing computer-generated flyovers, are available to the general public from commercial suppliers—inquiries may be directed to the Jet Propulsion Laboratory's Public Information Office in Pasadena, California.

Last of Magellan's original mission objectives, the low-latitude Gravity field

survey began at the start of Cycle 4 last September. Each cycle lasts about eight months, the time it takes Venus to rotate once below Magellan's near-polar orbit. To obtain Gravity data, the spacecraft only had to send an unmodulated downlink carrier signal, which, per normal operations, is coherent with a highly stable uplink generated by the Deep Space Network, JPL's worldwide tracking system. The gross Doppler shifts induced by Earth's rotation, Venus' and Earth's orbital motion, the spacecraft's orbit around Venus, and even solar radiation pressure, were all removed, as was a component introduced by intervening plasma. The residual Doppler shifts were the result of miniscule spacecraft accelerations, on the order of micrometers per second squared, resulting from variations in mass distribution on Venus. These Gravity measurements offer a "view" of mass distribution at and below the surface. William Sjogren of JPL, Principal Investigator for the Gravity experiment, waited patiently for his team's turn to conduct Gravity observations of the whole planet. During Cycles 1 through 3, the spacecraft's high-gain antenna (HGA) had to be used for radar mapping, and not until Cycle 4 was it free to be pointed to Earth for the 30 minutes before and after periapsis for the Gravity experiment. With Magellan's elliptical orbit, meaningful Gravity data could be taken only for that portion of the orbit plus and minus about 30° true anomaly from periapsis, which during Cycle 4 occurred at about 10° north latitude.

But there are many features in Venus' higher latitudes which could be better understood if Gravity field data were available all the way to the poles. One way to obtain these data would be to launch a completely new mission to Venus to conduct a global Gravity field survey from a circular orbit. But Magellan is at Venus now, and it

would be fully capable of providing a global Gravity field data set, if only its elliptical orbit could be circularized. Half a tank of propellant remained at the end of the Cycle 4 low-latitude Gravity survey, but this amount would not be nearly enough to reduce apoapsis from 8500 km to the desired few hundred km.

Aerobraking Magellan has long been viewed as a possibility, and this is currently being undertaken in Magellan's Transition Experiment, TEx, which began May 25, 1993. Since the spacecraft was never designed for atmospheric entry, this risky experiment is only appropriate now that Magellan has met and exceeded all of its originally planned mission objectives. TEx was initiated by firing the monopropellant hydrazine thrusters near apoapsis to lower the periapsis altitude, bringing the spacecraft down into denser levels of the Venusian atmosphere. A periapsis altitude corridor around 140 km above the surface has been the target. The deceleration induced by aerodynamic drag in Venus' atmosphere near periapsis is reducing the apoapsis altitude. While accomplishing the large, desired reductions in apoapsis altitude, this also has the effect of reducing periapsis altitude to a lesser degree. The latter is carefully controlled, using Magellan's thrusters for OTMS when the spacecraft is near apoapsis. The periapsis altitude corridor is constrained by higher dynamic pressure at lower altitudes, and bounded by too time-consuming an aerobraking process at higher altitudes. The spacecraft is being commanded to steer an attitude that trails the HGA in the free molecular "wind," with the back side of the solar panels flat-on, presenting about half the spacecraft's total cross-sectional area to the velocity vector. The sensible drag portion of each orbit increases from 4 to about 25 minutes throughout the duration of TEx, imparting a dynamic pressure in the neighborhood of

0.3 N/m². The orbital energy being removed as apoapsis altitude decreases, must, of course go somewhere: it is entirely taken out as heat built up on the spacecraft by friction with the atmosphere, then radiated quickly away into space, Maximum temperatures being tolerated are 160° C on the solar panels, and 180° on the HGA.

Commands are kept on the shelf at JPL, ready to send at a moment's notice to initiate OTMS to maintain periapsis altitude within the desired corridor. The actual software routines for executing the OTMS are stored onboard the spacecraft, and only require an "enable" to be sent in real time. An additional command is available to initiate an emergency OTM which would take the spacecraft up out of the sensible atmosphere, in case major problems should arise. Our highest priority is keeping the spacecraft safe.

TE_x is planned to last about 70 days, and is divided into two phases, the main phase and the end game. During the main phase of TE_x, expected to occupy around 60 days, the total effect of Venus' gravity field will have a larger effect than does atmospheric drag in lowering the periapsis altitude. During most of the end-game phase, the reverse is true.

Magellan will be encountering the day side of Venus' atmosphere in the main phase of TE_x. Thanks to studies by Dr. Gerald Keating of NASA Langley using Magellan and Pioneer-12 data (recall Pioneer recently burned up entering Venus' atmosphere after twelve years of orbital operations), much is known about the day side atmosphere. However, during the end-game phase of TE_x, Magellan will begin to

enter the night side atmosphere, for which existing data reveal large density fluctuations and greater uncertainty. It is highly desirable to complete TEx within a maximum of 80 days to avoid a handful of negative factors, including atmospheric density waves and the uncertainties in the night side environment, flight team fatigue, adverse effects from the gravity field, as well as DSN resource availability.

The TEx operation is being carried out differently from any previous operations, in that a looping program is running the spacecraft rather than a finite sequence of stored commands. This loop decrements its own period, based on parameters sent frequently from Earth, to adapt its on-orbit schedule of operations to the ever-shrinking orbit duration. There are two orbital activity profiles being executed on alternating orbits: "Starcal" orbits alternate with "OTM" orbits. On a starcal orbit, the spacecraft first assumes the prescribed HGA-trailing attitude for aerobraking, under control by AACS as it follows a stored set of quaternion polynomial coefficients (QPC). This takes the HGA off earthpoint several minutes prior to the sensible drag pass near periapsis. Several minutes after the sensible drag pass, the spacecraft stops following the QPC set, and maneuvers to place its roll axis perpendicular to a plane containing two specific bright stars. It then rotates about the roll axis so that the on-board star scanner can observe the position of each star. The AACS uses this data to update its attitude knowledge and gyro drift rate bias. After the starcal, the spacecraft maneuvers to place the HGA on Earthpoint. It then pauses two minutes to allow the DSN to lock receivers and telemetry processors to the downlink, then it reads out data from RAM containing temperatures and other measurements taken during the just-completed drag pass. This 10-minute downlink is transmitted at 1200 bits per second over the S-band radio link. The flight team uses these data to evaluate the spacecraft's

immediate health, and to decide which, if any, commands must be uplinked next. The spacecraft next maneuvers to an attitude which provides thermal control, and places the Medium Gain Antenna, the large cone-shaped structure on one side of the spacecraft, on Earthpoint. Downlink signals for tracking the spacecraft, and 40 bit-per-second telemetry are then received by the DSN. From this point, the next orbit begins, and the spacecraft again maneuvers to the aerobraking attitude.

On an OTM orbit, the spacecraft places the HGA on Earth immediately after the drag pass, waits 2 minutes for DSN lockup, and reads out aerobraking engineering data from memory. Then it maneuvers to an attitude appropriate for performing an OTM, which it will actually perform near apoapsis only if it has just been enabled by command from Earth.

The frequency of OTMS planned during TEx is increasing from about three per week in the beginning to a grueling workload of more than one per day late in the end game. Magellan's orbit period was 3.25 hours at the beginning of TEx, but it will be shrinking to about 100 minutes by circularization. Working a constantly changing orbit activity profile for the spacecraft is a challenge, since the DSN continuously requires accurate radio frequency and event-time predictions to track the spacecraft. Earth-received radio frequencies vary with the location of the spacecraft in its orbit since the Doppler shift varies greatly from one part of the orbit to another. At the beginning of TEx, however, the plane of Magellan's orbit was nearly "face on" as viewed from Earth, fortunately reducing to nearly zero any such Doppler-induced frequency offsets. The orbit plane approaches "edge on" late in the end game, wielding its maximum Doppler

effects and making orbital-event time predictions more critical.

Once apoapsis has been lowered sufficiently, the periapsis altitude will be raised out of the denser atmosphere to achieve a nearly circular orbit. TEx's objectives having been met, a Gravity field survey can then be made having near-uniform resolution at all latitudes.

Will Magellan survive aerobraking to achieve a nearly circular orbit? If it does, will the project be able to obtain funding for additional eight-month cycles of a pole-to-pole Gravity survey? Time will tell, It has been proposed that circular orbital operations be carried out by a "lean, mean Gravity team" at JPL and Martin Marietta, which would operate at an absolutely minimum funding level to collect circular-orbit Gravity data for storage in the archives for access by researchers. While no new money was included in NASA's 1993 budget request for Magellan operations, enough funding for the "lean, mean" operation may come from sources internal to NASA and JPL.

The work described here is carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration,

Illustration Captions

Figure 1. (Color Image P-39225)

Magellan Synthetic Aperture Radar (SAR) data are mapped onto a computer-simulated globe for a view of Venus' surface centered at 180° East longitude. Magellan mapped 98% of the surface of Venus with SAR, radar altimetry, and radiometry. NASA/JPL Image.

Figure 2. (Black& White Graph)

Comparison of Pioneer-1 2's raw Gravity data at S-band with Magellan's at X-band, from the same Venus longitude and periapsis altitude, reveals the lower noise and better visibility of smaller features in the Magellan data, typical throughout the Cycle 4 Gravity survey. Periapsis crossing is near the center of the graph. Courtesy W. L. Sjogren, NASA JPL.

Figure 3. (Black& White Graph)

Orbit trim maneuvers begin 25 May (Day of Year 145) bringing Magellan's periapsis altitude into denser atmospheric levels for aerobraking to a nearly circular orbit.

Repeated trim maneuvers will maintain the spacecraft within the nominal aerobraking design corridor until apoapsis has been reduced sufficiently after about 70 days or more.

Figure 4. (Color Image P-39375) Refer to PIO text attached.

Figure 5, (Color Image P-401 75) Refer to PIO text attached.

Figure 6. (Color Image P-38270) Refer to PIO text attached,

Figure 7. (B & W Image P-39230) Refer to PIO text attached,

Figure 8. (Color image P-40697) Refer to PIO text attached.

Figure 9. (B & W Image P-38857) Refer to PIO text attached.